ACTS BROADBAND AERONAUTICAL EXPERIMENT

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ABSTRACT

In the last decade, the demand for reliable data, voice, and video satellite communication links between aircraft and ground to improve air traffic control, airline management, and to meet the growing demand for passenger communications has increased significantly. It is expected that in the near future, the spectrum required for aeronautical communication services will grow significantly beyond that currently available at L-band. In anticipation of this, JPL is developing an experimental broadband aeronautical satellite communications system that will utilize NASA's Advanced Communications Technology Satellite (ACTS) as a satellite of opportunity and the technology developed under JPL's ACTS Mobile Terminal (AMT) Task to evaluate the feasibility of using K/Ka-band for these applications. The application of K/Ka-band for aeronautical satellite communications at cruise altitudes is particularly promising for several reasons: (1) the minimal amount of signal attenuation due to rain; (2) the reduced drag due to the smaller K/Ka-band antennas (as compared to the current L-band systems); and (3) the large amount of available bandwidth. The increased bandwidth available at these frequencies is expected to lead to significantly improved passenger communications - including full-duplex compressed video and multiple channel voice. A description of the proposed broadband experimental system will be presented including: (1) applications of K/Ka-band aeronautical satellite technology to U.S. industry; (2) the experiment objectives; (3) the experiment set-up; (4) experimental equipment description; and (5) industrial participation in the experiment and their benefits.

APPLICATIONS

There is presently a demand for high quality, reliable, voice and data satellite communication links between aircraft and ground to improve air traffic management services and to meet the growing demand for passenger communication services. The former are of importance as they should result in increased passenger and crew safety and should reduce flight time and operational costs by optimizing the aircraft's flight path . The latter is likely to be of concern to the airline companies in order to maintain customer satisfaction and allegiance.

Since 1991, Inmarsat has provided a single channel packet data link at 600 bps, nominally, and a single channel voice, data, or FAX link at 9.6 kbps using several antenna designs. Both channels are established at L-band using Inmarsat I and II satellites. The American Mobile Satellite Corporation (AMSC) will also be providing these services as well. Furthermore, both Inmarsat and AMSC have recently began offering or plan to offer multiple voice and data channel services.

As these systems become implemented and more widely used at L-band, and the benefits provided by their operation are realized, it is likely that the communication role envisaged for aeronautical satellite communications will grow. Concepts such as providing passengers with an "office in the sky," i.e. voice, data, FAX, and compressed video teleconferencing, or real-time news and sports broadcast will expand. Air crew services such as real-time transmission of weather maps or compressed video transmission from the cockpit or cabin for security may become attainable. Additional demand for the planned telecommunication services mentioned above as well as for these new services will motivate a need for more spectrum than is likely to be available at L-band. The application of K/Ka-band for aeronautical satellite communications could be used as to enhance the mobile satellite capabilities at L-band as these demands increase [1].

In addition to these commercially oriented needs, recent events in the Middle East (Persian Gulf War) and other potential hotspots around the world have suggested that the development of this type of technology would be extremely beneficial to our nations military efforts. For these needs, the emphasis would be on providing compressed video imaging from an aircraft back to a fixed terminal, as opposed to the commercial emphasis of a broadcast application (compressed video imaging from a fixed terminal to the aircraft).

EXPERIMENT CONFIGURATION

The ACTS Broadband Aeronautical Experiment has been designed to not only prove the feasibility of K/Ka-band aeronautical mobile satellite communications, but to design the overall system in a manner that would allow for easy technology transfer to U.S. industry. The aeronautical system configuration consists of a fixed (ground-based) terminal, ACTS, and an aircraft terminal as shown in Figure 1. The fixed terminal consists of a communications terminal mated to the High Burst Rate Link Evaluation Terminal (HBR-LET) RF hardware including the 4.7 m antenna. The aircraft terminal's architecture will be similar to that of the ACTS Mobile Terminal [2]. In the forward direction (fixed station-to-aircraft) the fixed terminal will transmit a data and a pilot signal to ACTS. ACTS will then transmit these signals to the aircraft terminal while operating in the Microwave Switch Matrix (MSM) mode of operation (a bent pipe mode). The signal in the forward link will beat a maximum data rate of 384 kbps. On the return link (aircraft-to-fixed station) the signal transmitted from the aircraft terminal will consist of a data signal with a maximum data rate of 112 kbps.

Two transponders will be utilized on ACTS for this experiment. One transponder will be used to support the fixed station-to-aircraft forward link signals and the other the aircraft-to-fixed station return link. The first transponder will be configured with the 30 GHz Cleveland fixed beam for the uplink and a 20 GHz spot or steerable beam for the downlink to the aircraft. The second transponder will be configured with a 30 GHz spot or steerable beam for the uplink and the 20 GHz Cleveland fixed beam for the downlink.

EXPERIMENT OBJECTIVES

The primary objectives for the ACTS Broadband Aeronautical Experiment are to:

(1) Characterize and demonstrate the performance of the aircraft/AC TS/AMT K/Ka-band communications link for high data rate aeronautical applications. This includes the characterization of full-duplex compressed video, and multiple channel voice and data links.

(2) Evaluate and assess the performance of current video compression algorithms in an aeronautical satellite communications link.

(3) Characterize the propagation effects of the K/Ka-band channel for aeronautical communications during take-off, cruise, and landing phases of aircraft flight.

(4) Evaluate and analyze aeronautical satellite communication system concepts common to both L-band and K/Ka-band communication systems.

(5) Provide the systems groundwork for an eventual commercial K/Ka-band aeronautical satellite communication system.

The experimental system performance will be evaluated both quantitatively and qualitatively. Qualitatively, the principle criterion will be the ability to maintain a full-duplex video, or multiple channel voice or data link while the aircraft is in the cruise phase of flight, as well as during take-off and landing. Quantitatively, the link performance is a direct function of the bit error rate (BER). The BER in turn is a function of the received signal to noise ratio and its stability, frequency offsets including Doppler and Doppler rate, and other effects on the link such as phase noise, aircraft shadowing, and possibly multipath. The quantitative evaluation of system performance will therefore be presented in terms of two criteria: (1) the ability to maintain a minimum given received signal level, which is dependent on the performance of the aircraft antenna system in the aeronautical environment as well as the scanning (or steerable) beam characteristics of ACTS, and (2) the BER performance versus received bit signal energy to noise density ratio, E_b/N_o with the different channel disturbances as parameters. The quantitative assessment will include a comparison between theoretical results (analysis and simulation), laboratory measured results, and experimental results for various channel conditions encountered.

The required BER for video codecs are typically between 10^{-5} and 10^{-6}, higher than is normally required for voice communications (BER of approximately 10^{-3}). When operating at higher BER's, most video codecs will have serious audio distortion and intermittent video "tiling" effects. Therefore, in order to select a suitable video codec, a tradeoff between required BER for distortionless operation and data rate versus the available link margin will be performed. Currently, there are many commercial video compression products available. These products employ a variety of video compression techniques, implemented in a combination of hardware and software. Ideally, several video codecs will be tested in this experiment, as none have been designed for transmission over a channel with time-varying characteristics such as the aeronautical satellite channel.

The aeronautical environment is characterized by: (1) large variations in the elevation angle to the satellite in the aircraft frame of reference; and (2) blockage of the line-of-sight to the satellite by the aircraft structure. Both effects are due to aircraft banking and changes in attitude angle during flight. An in-depth study of these effects will help in future designs of aeronautical satellite communication systems. Among the system parameters that will be most directly affected by these characterizations are the antenna scanning angle, the antenna beamwidth, and the antenna placement on the aircraft. Measurements will be made to characterize the propagation effects due to clouds, possible aircraft blockage, rain attenuation on both the uplink and the downlink, and other environmental conditions during take-off, cruise, and landing phases of flight. These measurements will be based on various transmitted and received beacon and pilot signals. An attempt will be made to categorize and separate the sources of channel degradation (cloud effects, aircraft obstruction, rain effects, etc.). Cumulative fade distributions will be computed for the different channel conditions encountered, and the associated terminal performance identified.

Several general aeronautical system (common to both L-band and K/Ka-band aeronautical satellite communications systems) concepts will be studied during this experiment including: (1) compressed video transmission and reception techniques; (2) multiple cabin and cockpit channels with call priority assignments; and (3) the aeronautical satellite link connection with the aeronautical telecommunications network. A thorough study of these system parameters will greatly enhance future aeronautical satellite system design and performance. A study of the compressed video transmission and reception techniques will assess the performance of the video compression units over the K/Ka-band mobile satellite communications channel. These units will further be categorized by the subject of the video transmission (Can the video compression unit handle video teleconferencing? How does the unit handle rapid motion?, etc.). Another system concept that will be looked at is the multiple channel system with priority assignment. For this set-up, several data or voice link lines will be established, with the highest priority being given to the aircraft cockpit, and the lesser priority being given to passenger communications. Finally, recommendations for the design of the aeronautical satellite communications equipment will be accomplished in a manner such as to ease the integration of the equipment with the Aeronautical Telecommunications Network (ATN).

From the data collected from this experiment, and the ensuing analysis, recommendations about the design of a practical and cost efficient commercial K/Ka-band aeronautical satellite communications system will be developed. This overall system design recommendations will not only include specifications for the aeronautical and ground communications terminal, but also for the satellite design. Specifications for the performance of the terminal subsystems (e.g., modem and video compression unit) will also be included in the recommendations. Some of the system specifications will include typical Doppler offsets that a commercial system should be expected to handle, typical scanning angles of the antenna subsystem due to the banking motion of the aircraft, as well as the overall performance of the various video compression units in the presence of a K/Ka-band mobile satellite communications channel.

EXPERIMENT EQUIPMENT

The necessary equipment for this experiment includes an aeronautical mobile terminal, a fixed terminal, an aircraft, and ACTS. The aeronautical terminal and fixed terminal architectures are similar to that of the AMT for the land-mobile experiments as described in [3]. There are, however, several distinct differences between the two terminal developments: (1) the development of an aeronautical antenna that can track in elevation, as well as in azimuth; (2) the development of a higher rate modem (up to 384 kbps as opposed to up to 64 kbps) than for the land-mobile experiments; and (3) the use of a (several) video compression unit(s) in addition to a speech codec. A more complete description of this equipment can be found in [2]. A detailed description of ACTS can be found in [4].

LINK BUDGETS

The forward (data only) and return link budgets for the experimental configuration are presented in Table 1. ACTS' west scan sector beam is used to link to the aircraft; the EIRP and G/T of the edge of beam contours are taken to be 59.00 dBW and 15.00 dB/°K, respectively. The accuracy of these values is +/-1.00 dB. ACTS' Cleveland fixed beam is used for communications with the fixed terminal. The EIRP and G/T at the center of the beam are 69.50 dBW and 21.25 dB/°K, respectively. The aeronautical terminal G/T assumed is -5.00 dB/° K. The modulation scheme assumed is BPSK with a rate 1/2, constraint length 7, convolutional code, with soft-decision Viterbi decoding. A BER of 10^{-6} is assumed to be achieved at an E_b/N_o of 4.5 dB. A loss of 3.00 dB due to modem implementation, phase noise, and frequency offset effects are assumed. On the forward link both data and pilot signals (equal power) are transmitted (the link budget is shown strictly for the data channel). The total fixed terminal EIRP is 68.00 dBW. The resulting forward (at 384 kbps) and return link performance margins (at 112 kbps) are 3.29 dB and 2.89 dB, respectively.

EXPERIMENT RESULTS AND BENEFITS

The development and execution of this experiment will be accomplished in conjunction with U.S. industrial participation. A broadband aeronautical working group is being formed to assist with this effort. Member of this working group will come from a wide variety of interests in U.S. industry including: (1) aircraft manufacturers, (2) airline carriers, (3) satellite service providers, (4) aeronautical avionics manufacturers, (5) video compression companies, (6) broadcasters, (7) other government agencies, and (8) government regulators. Input from these groups during the development of the experiment will shape the experiment in a way that will provide for an efficient transfer of the technology and system concepts to a commercial venture. Their input will include: assistance with the experiment conceptual development, equipment development, use and operation of an aircraft, and overall experiment execution. Active participation by U.S. industry in this experiment will help to stimulate the commercialization of this service. It is anticipated that a commercially operated system that would provide compressed video broadcasts for passengers could be in service as early as the turn of the century.

SUMMARY

The ACTS Broadband Aeronautical Experiment will help verify that K/Ka-band mobile satellite technology could be useful in meeting increased demands for aeronautical mobile satellite communication services. The minimal amount of signal attenuation due to rain during the cruise phase of flight, the reduced drag due to the smaller K/Ka-band antennas (as compared to the current L-band systems), and the large amount of available bandwidth makes the development of a K/Ka-band aeronautical mobile satellite system a logical choice for such non-critical passenger services as live video broadcasts of news and sports events, voice, FAX, data, etc. and other needs. Planned active industrial participation in this experiment will allow for the conclusions, technology, and system concepts to be easily transferred to U.S. industry to develop a commercial K/Ka-band aeronautical mobile satellite communications system.

REFERENCES

[1] Nguyen, T., et. al., "ACTS Aeronautical Experiments," AIAA Conference 1992, ppg. 1769-1781.

[2] Abbe, B. S., et. al, "ACTS Broadband Aeronautical Experiment ," ACTS Conference 1992.

[3] Agan, M. J., et. al., "The ACTS Mobile Terminal: Poised for ACTS Launch," IMSC, June 1993.

[4] Wright, D. and Balombin, J., "ACTS System Capability and Performance," AIAA Conference 1992, ppg. 1135-1145.

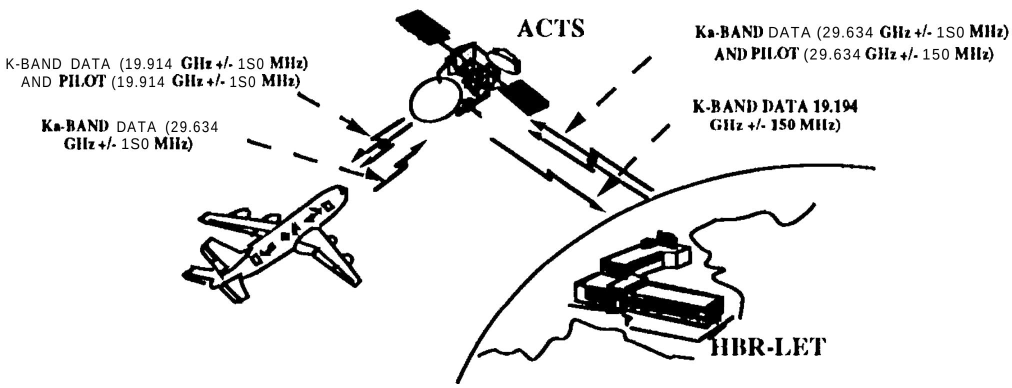

Figure 1 ACTS Broadband Aeronautical Experiment Set-Up

Table 1 Broadband Aeronautical Experiment Link Budgets

PARAMETER	FORWARD LINK	RETURN LINK
Transmitter Parameters		
EIRP, dBW	65.000	34.000
Pointing Loss, dB	-0.800	-0.500
Radome Loss, dB	0.000	-0.200
Path Parameters		
Space Loss, dB	-213.480	-213.340
Frequency, GHz	29.634	29.634
Range, km	38000.000	37408.000
Atmospheric Attenuation, dB	-0.360	-0.360
Receiver Parameters		
Polarization Loss, dB	-0.130	-0.850
G/T, dB/K	21.250	15.700
Pointing Loss, dB	-0.220	-0.320
Bandwidth, MHz	900.000	900.000
Received C/N_o, dB-Hz	99.860	62.780
Transponder SNR_{IN}, dB	10.320	-26.770
Effective Hard Limiter Suppression, dB	-5.000	-1.050
Effective Hard Limiter SNR_{OUT}, dB	5.320	-27.820
Transmitter Parameters		
EIRP, dBW	55.200	24.180
Pointing Loss, dB	-0.320	-0.220
Path Parameters		
Space Loss, dB	-209.890	-210.030
Frequency, GHz	19.914	19.914
Range, km	37408.000	38000.000
Atmospheric Attenuation, dB	-0.500	-0.500
Receiver Parameters		
Polarization Loss, dB	-0.850	-0.130
Radome Loss, dB	-0.100	
G/T, dB/K	-5.000	27.000
Pointing Loss, dB	-0.500	-0.500
Downlink C/N_o, dB-Hz	66.640	68.400
Overall C/NO, dB-Hz	66.640	60.880
Required E_b/N_o (AWG N), dB	4.500	4.500
Modem Implementation Loss, dB	1.000	1.000
Loss Due to Frequency Offsets, dB	1.000	1.000
Required E_b/N_o, dB	6.500	6.500
Loss Due to ACTS Phase Noise, dB	1.000	1.000
Data Rate, kbps	384.00	112.000
Performance Margin, dB	3.290	2.890